HYDROGEN FUELED HYPERSONIC TRANSPORTS

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INTRODUCTION

Aeronautical vehicle development beyond $M \approx 3$ has been restricted in large measure by limitations in the state of technology of high-temperature, high-strength materials; for example, application of turbojet propulsion is restricted to $M < 3.5$ by turbine-blade temperature limits and uncooled airframes begin to require superalloy metals at Mach numbers somewhat higher than this. Whereas, steady progress has been made in research on high-temperature materials for advanced high-speed aircraft, the most stimulating finding for the prospects of hypersonic cruise aircraft has come out of recent systems studies closely tied to continuing research in all of the disciplinary areas of aerodynamics, propulsion, and structures. This finding is the clear indication of feasibility of hypersonic cruise vehicles actively cooled over most of the airframe surface by the residual heat sink of the liquid hydrogen fuel. It is toward such projected aircraft that the present paper is primarily pointed. Results of these recent NASA studies, made in-house and under contract, will be freely drawn upon and referenced. It is significant to the future prospects for a hypersonic transport (HST) that it may avoid or overcome some of the environmental problems so critical to the decision to halt development of the U.S. SST.

One potential traffic market for the HST is indicated in Figure 1 which shows a projection of the international passenger traffic between major world areas for the year 1990 and the ranges associated with this traffic. A number of such projections have been made (refs. 1 through 3) and although there is some disagreement as to the absolute magnitude of the passenger traffic, the distribution by range of these projections is generally in good agreement. The dashed bars in Figure 1 indicate possible future exchange of travelers with the Communist countries. Two major points are made from this figure: (1) the high rate of travel predicted for the year 1990 which, from a standpoint of air traffic congestion, implies the need for aircraft with large passenger capacities (high payload), and (2) the indication that about 90 percent of this traffic will require aircraft with range capabilities between 3000 and 6000 n. mi.

From a standpoint of convenience and comfort, it is of interest to consider the duration of the flights associated with these long ranges. Figure 2 shows a comparison of the trip times (wheels rolling to wheels stopped) associated with aircraft having cruise speeds ranging from subsonic ($M = 0.85$), supersonic ($M = 3$) to hypersonic ($M = 8$), for representative international flights. The sizable time savings available through hypersonic flight are obvious, particularly for the longer ranges.

Other factors which will influence the nature of future transport aircraft stem, for example, from the growing concern over atmospheric pollution, a fact which the aeronautical engineer must accept in designing environmental acceptability into his product. The speed, range, and environmental advantages of the HST will probably demand a premium fare; at the same time, it must fit the airway and airport systems and cannot price itself out of the market, hence must have DOC's, airframe life, and so forth, not too much different from the jumbo jets.

A distinguishing feature of the HST will be the use of liquid hydrogen fuel (LH_2), which has 2-3/4 times the energy per pound of conventional JP fuel (ref. 4). (See Fig. 3.) The higher energy per pound of LH_2 more than compensates for the secondary effect of a reduction in aerodynamic efficiency ascribable to housing the low density fuel. The large heat-sink capacity of liquid hydrogen – 10 percent of the combustion energy – allows active cooling of the airframe (as well as the scramjet engine), offering the possibility of using conventional aluminum structures and attaining airframe lifetimes comparable to the jumbo jets.

The general appearance of one concept of an HST as illustrated in Figure 4 is noteworthy in its similarity to the current SST concepts, a fact not too surprising since, for the active-cooling approach, materials are similar and passenger windows appear feasible. Because of the low density of LH_2, the aircraft will have a large body volume which will result in a structural weight fraction higher than that for JP-fueled aircraft and a nominal increase in the aerodynamic drag of the airplane. It is likely that such an aircraft will be streamlined through blending of the wing and fuselage to get an optimum compromise between containment of the low density fuel and aerodynamic efficiency.

HYPERSONIC TRANSPORT PROPULSION

A primary feature of the HST will be its air-breathing, regeneratively cooled, hydrogen-fueled scramjet engines. The superior performance potential of the hydrogen burning ramjet is clearly seen in Figure 5 in terms of the propulsive efficiency factor, specific impulse (pounds of thrust per pound per second of fuel or propellant burned), as a function of Mach number. For hydrogen-oxygen rockets, values of specific impulse are limited to something less than 500 since rockets must carry their own oxidizer, but these values are, of course, available in airless space. The large increases for airbreathers over rockets is evident for both kerosene and hydrogen-fueled systems to about $M = 10$. For both kerosene-fueled and hydrogen-fueled air-breathing turbojets, ramjets, and supersonic-combustion-ramjets (scramjets) the downward trends with Mach number are similar with the very large advantage for hydrogen burners reflecting the higher energy per pound of hydrogen. Turbojets can be used for take-off (where ramjets are inoperable) and acceleration to $M \approx 3.5$. As a Mach number about this value is approached, the stagnation or ram temperature is increasing to such a value that diminishingly less fuel can be added before exceeding the permissible turbine-blade temperature, thus the thrust is dropping rapidly. In the range of Mach number, the ramjet (subsonic combustion), which has no compressor or turbine and uses only the ram pressure of flight, comes into its own. Its effectiveness survives to about $M = 7$ at which point several factors point to the use of scramjets (supersonic combustion). By ramjet we have meant subsonic combustion; in fact, combustion is at as low a velocity as possible to minimize the entropy increase in the combustion process. For the subsonic combustion ramjet, as Mach number increases, both pressure and temperature in the combustion chamber increase, leading to high structural weight for pressure containment, high heat transfer, and large cooling requirements. Most significant, however, is the fact that the high temperatures also introduce significant dissociation of the combustion products. Most of this dissociation energy (which would otherwise be available for thrust) is lost due to lack of recombination before expansion to ambient conditions. All of these factors point to the use of supersonic combustion which lowers the pressure and temperature in the combustion chamber at some increase in entropy gain in the combustion process at higher velocities. The net effect is overall gain for the scramjet mode at $M \approx 7.0$. The scramjet can continue to provide thrust greater than drag for conceptual vehicles flying at Mach numbers in excess of 12.0.

Propulsion Technology

The use of LH_2 in turbojet engines is by no means virgin territory. In 1957, NASA's Lewis Research Center successfully operated a J65 turbojet engine using hydrogen as a fuel (ref. 5). A liquid hydrogen fuel tank and a ram-air heat exchanger were mounted on the left wing of a B-57 airplane and a high-pressure helium tank was mounted on the right wing (Fig. 6). The heat exchanger was used to gasify the hydrogen before entering the engine, and the helium was used for pressurizing the LH_2 fuel tank and purging the fuel system. Take-off and climb to 49,000 feet altitude and a speed of around $M = 0.72$ were accomplished by operating both engines on conventional JP-4 fuel. One engine was then operated on a mixture of hydrogen and JP-4 and then on hydrogen alone for approximately 20 minutes. Several flights were made without incident. Although specific fuel consumption during the flight tests was not reported, tests in ground facilities simulating flight conditions indicated that the specific fuel consumption of JP-4 fuel was 2.73 times that of hydrogen, thus realizing the gains expected from hydrogen fuel.

Peturning to ramjets, extensive research over about the past 10 years has produced an advanced level of technology for applications up to about $M = 5$. Ramjet flight articles, primarily missiles, produced in this country and abroad, have been restricted to hydrocarbon fuels. Although limited to ground-based facilities, hydrogen-fueled ramjet engines have received considerable research effort. Both subsonic and supersonic combustion ramjet engines have been successfully demonstrated and, in most cases, the high-performance levels anticipated were achieved. A brief resume of this work is presented in reference 6. One example of the work being done in this field is the NASA Langley Hypersonic Research Engine (HRE) Project. Initially, the objectives of this project were to develop a hydrogen-burning ramjet engine for operation between Mach numbers of 3 and 8 with dual mode subsonic and supersonic combustion capability and to conduct ground-based and flight experiments which would prove design and fabrication techniques and provide needed engine research data. After the flight tests, which were to have been carried out using the X-15 research airplane as a test bed, were canceled due to the termination of the X-15 program, an expanded ground-test program was formulated and is still in progress. A simplified cross section of the HRE that evolved is shown in Figure 7. The HRE is an axisymmetric, variable geometry engine (18 inches in diameter and 84 inches long) with a translating center spike to give needed variable geometry for operation over the Mach number range; for example, the translating center body positions the shockwave from the spike on the cowl lip from Mach 6 to Mach 8, minimizing flow spillage. From the sketch, one can see that as Mach number is increased the fuel injection and combustion move forward in the engine. A so-called structural assembly model (SAM) of the HRE, which is a realistic flight weight engine (although for ground tests) incorporating subsystems, controls, and relatively sharp hydrogen-fuel-cooled leading edges for both inlet cowl and the internal struts, has been tested in the Langley 8-foot high-temperature structures tunnel (Fig. 8). This series of tests provided a solid demonstration that a flight-weight, regeneratively cooled ramjet engine could operate in the $M = 7$ environment. Although these tests were carried out with full flight temperature, the test stream of hydrocarbon-air combustion products did not contain enough oxygen to permit combustion tests. The final phase of the HRE project will thus include tests of a "boiler plate," water-cooled, hydrogen-burning model in a new facility at our Lewis Research Center wherein true temperature air up to $M = 7.0$ is provided, and combustion experiments can be made over a Mach number range from 5 to 7.

Under the stimulus provided by the HRE project, a number of long-range basic scramjet problems have been brought into focus for which new research has been organized. The research programs reflect the fact that efficient hypersonic cruise vehicles should capitalize on the very strong interaction among the structural, propulsive, and aerodynamic features of vehicle design. One major research objective is, for example, to develop scramjet engine concepts that minimize fuel-cooling requirements so that a maximum of the residual hydrogen-fuel heat sink is available for airframe cooling. Features of such engines that will reduce the internal heat load are readily identified as follows: supersonic combustion, nonannular ducts having low ratio of wetted area to flow area, short combustor length (efficient fuel injectors), short cowl lengths, large combustor area ratios, reduced pressures and reduced fuel injection near the duct walls, insulation, film cooling, and the use of the aircraft body for major parts of the inlet and nozzle functions. Using all of these features except insulation, we have designed and analyzed the scramjet concept shown in Figure 9. For comparison, the cooling requirements of an annular engine were also determined and the results are given in Figure 10, which shows the large reductions in cooling requirements (integrated over the engine length) for the three-dimensional rectangular-module design (see refs. 7, 8, and 9). For this study at $M = 6$, the small fraction of the total fuel-flow heat capacity needed for engine cooling leaves most of the hydrogen heat sink available for airframe cooling. The large margin shown available for airframe cooling at $M = 6$ diminishes with increasing Mach number due to growing engine-cooling requirements, however, studies have shown that actively cooled cruise vehicles may be feasible up to Mach numbers of 9 to 10.

HYPERSONIC TRANSPORT STRUCTURE

Before addressing the prospects for actively cooled airframes, first consider the case for "hot" structures, which dispose of a major portion of the heat load through radiation. Shown in Figure 11 is a "typical" temperature distribution for upper and lower surfaces of an $M = 8$ HST wherein aerodynamic heating input is balanced by radiation. The feasibility of the "hot" structure rests on the fact that the radiation equilibrium temperatures of cruise vehicles tend to fall within the possible working-temperature ranges of the so-called superalloys and the refractory metals. A cross section of a radiation-cooled wing structure that has evolved from research studies is shown in Figure 12. Here the primary structure is made up of superalloys or refractory metals protected by both insulation and heat shields. Major strides toward solving the problems of thermal stress have been made through the use of nonredundant structures and corregated shear webs (ref. 10). The thin heat shields which protect the primary structure are typically 0.01-inch to 0.02-inch thick and are attached to the primary structure by delicate clips in order to minimize conduction effects and save weight. When the heat shields expand due to high temperatures, sliding joints sealed by flexible bellows are necessary to prevent hot boundary-layer air from leaking into the substructure and causing hot spots. Whether or not aircraft structures of this type can withstand the rigorous demands of commercial aircraft operations and maintain long airframe lifetimes is yet to be determined.

Having suggested the obvious difficulties of routine airline-type operation of red-hot structures and having indicated the feasibility of scramjet engines with low cooling requirements, it remains to be stated that realistic actively cooled structures can be envisaged for the airframe of the hypersonic cruise aircraft. If it were possible to cool the skin and primary structure of the aircraft to around 500° F, it would be possible to construct the aircraft of titanium, using current materials and construction technology. Cooling the airframe to 200° F would not only allow the hypersonic aircraft design to take advantage of years of experience in building aluminum alloy airplanes, but would also open the door to the use of boron-aluminum composites. Preliminary studies (refs. 7 and 8) have in fact indicated that an airframe cooling system using a secondary coolant which is circulated internally in the airframe and used to carry the heat load from the airframe to a central hydrogen-fuel-cooled heat exchanger is feasible and could reduce the airframe temperature of a Mach 6 airplane to levels which would permit the use of titanium, and, with limited heat shielding, the use of aluminum. The secondary coolant might be a water-ethylene-glycol solution for aluminum alloy cooling or a silicone-base fluid such as Dow-Corning DC-331 for titanium alloy cooling. A typical cooled wing panel, shown in Figure 13, has been analyzed with respect to coolant-tube spacing, temperature gradients, and coolant flow rates. The studies have shown (ref. 11) that the physical proportions of the entire cooling system are quite reasonable (Fig. 14) and that the weight of the cooling system, including the plumbing and heat exchanger, may be more than offset by the savings in the weight of the airframe, heat shields, and insulation, as shown in Figure 15. The coolant (water-glycol) and its piping constitute the principal cooling system weight. Future studies will consider design criteria and system reliability in detail and determine the optimum panel concepts and secondary coolants for a variety of airframe materials, including composites.

An area of concern to either "hot" or actively cooled structures will be the containment of the LH_2 fuel at -423° F. Two concepts being examined at Langley are shown schematically in Figure 16. As shown in the sketch at the upper right for one concept, the LH_2 tank is protected by a layer of insulation. Unless air is prevented from coming into contact with the tank wall, cryopumping will occur, the air will liquify, and run down the tank wall. This condensation of the air results in high heat transfer to the fuel, reduces the effectiveness of the insulation, promotes damage due to freezing and thawing, and, due to selective liquefication, may cause a dangerous accumulation of liquid oxygen. In order to prevent air and moisture from entering the area, the space adjacent to the outer wall is pressurized with an inert gas such as nitrogen. A portion of the insulation nearest the tank wall has a small pore size to prevent the nitrogen from flowing down the tank wall and thus minimizes cryopumping.

Another concept, shown in the lower right portion of Figure 16, utilizes internal as well as external insulation. In this case, the internal insulation maintains the tank wall above the condensation temperature of air, however, cryogenic penetration of the internal insulation must be prevented. Although not indicated in Figure 16, an inert purging gas would probably be desirable for this concept when safety aspects are considered.

HYPERSONIC TRANSPORT OPERATIONS

Environmental Effects

Supersonic flight of SST's over the United States was prohibited by the Congress owing to the presumed unacceptability of the "sonic boom." An examination of the sonic-boom overpressures of aircraft of the SST weight class, shown as a function of cruise Mach number (Fig. 17), gives insight into a promising HST feature. For $M = 3$, SST-type aircraft, sonic-boom overpressures in the range of 1.5 to 3.5 psf are estimated; for HST-type aircraft at $M = 6$ to 8 overpressures have decreased to about 1 psf. Lower overpressures at hypersonic speeds follow principally from the higher cruise altitudes of HST's (around 100,000 ft). Should these lower sonic-boom overpressures be found acceptable when the advantages offered the air traveler by hypersonic flight are weighed against environmental aspects, overland travel would be revolutionized as shown in Figure 18. Since HST's would still have high sonic booms during the acceleration and climb to cruise altitude, these phases would be carried out over the ocean before heading overland; likewise, the HST would decelerate and descend over water. Transcontinental trips would require only one-third the time required for subsonic aircraft and a flight from Los Angeles to Paris could be made in around 2.5 hours.

Hydrogen-fueled aircraft may be more attractive than fossil-fueled aircraft from an ecological standpoint. A comparison of the environmental emissions of an HST and a hydrocarbon-fueled SST is shown in Figure 19 and is expressed in pounds of emittant per mile. The HST will emit no carbon dioxide, no carbon monoxide, no solid particles, or unburned hydrocarbons, and a smaller amount of nitric oxide than an SST - on the other hand, it will emit an amount of water vapor more than three times that for the SST. It must be stated that the effects on the environment of release of water vapor in quantities such as those from either a fleet of high-altitude SST's or HST's is not known at the present time.

Economic Aspects

As was mentioned in the opening remarks, if the HST is to become a reality, it must either offer the traveler unique capabilities for which the traveler is willing to pay a premium price or it must be economically competitive from a standpoint of direct operating cost. Although the HST would offer tremendous timesavings and convenience to the traveler, it is difficult to estimate passenger preference, particularly when connected to the purse string, therefore, one needs to compare direct operating costs of large transports as is done in Figure 20 for a subsonic jet (JP-fueled), an SST (JP-fueled), and a LH_2 fueled HST (ref. 4). The hashed areas represent the cost of flight crew, insurance, maintenance, and depreciation, while the open bars represent the cost of the fuel. An additional scale is shown on the right which reflects the effect of the relative price of LH_2 on the direct operating cost of the HST. Clearly, the economic competitiveness of the HST will be largely a reflection of the price of LH_2. It should be pointed out that the fuel cost for the JP-fueled aircraft represent present-day prices. Consider next the fuel price situation that might exist during the time period of the 1990's when the HST might become operational. Figure 21 shows a comparison of the relative cost per Btu of LH_2 as compared to JP fuel, for the past, present, and the future. With the onset of the space industry, the increasing demand for LH_2 drove the price steadily downward (data supplied to author by Vic Johnson, National Bureau of Standards, and John E. Johnson, Linde Division, Union Carbide Corp.) to about 16 cents per pound at present. Economic studies of hydrogen production (for example, refs. 4 and 12) have indicated that by merely increasing the quantity of LH_2 production, further sizable reductions in price would occur as shown by the hashed area. (An HST would typically use 200,000 pounds LH_2 per flight.) Continual improvement in production methods will also drive the price down. Electrolytically produced hydrogen might become more economically feasible at some future date if electric-energy costs are drastically reduced. Though fossil fuel prices (ref. 13) have remained fairly constant, they are predicted to gradually rise (refs. 14 through 16) due to the depletion of our reserves, increased cost of extraction, and our growing dependence upon imports. These price increases are reflected in the hashed area representing JP fuel. The cost of hydrocarbon fuels may rise even faster than shown if pressure from environmentalists continues. In the time period of the 1990's the cost of LH_2 is seen to be competitive with hydrocarbon fuel, particularly if other uses of hydrogen energy (refs. 17 and 18) continue to receive broader attention, making hydrogen the fuel of the future.

Technology Projection

Taken from reference 11, Figure 22 shows, from rather detailed system studies, that a hot-structure hypersonic transport weighing 750,000 pounds and carrying 300 passengers, and using current technology, would have a range of 6000 miles. Our detailed studies on the cooled structure permit realistic speculation on its potential advantages for future vehicles. It is stated in reference 11, that with cooling, a 15-percent structural weight reduction due to composites and a major reduction in cryogenic-tankage-insulation weight can be postulated. In addition, a modest 10-percent gain in lift-drag ratio (L/D) through refinements such as area ruling, twist, camber, and filleting has been included. A 12-percent increase in specific impulse is also believed to be obtainable from increases in component efficiencies over the nominal values used previously. And thus the 6000-nautical-mile range obtained with the hot vehicle could be extended to over 10,000 nautical miles through future technology, as seen in Figure 22. For comparison, the lesser gains estimated on a comparable basis for a JP aircraft are also shown. Although the additional HST performance is shown as an increase in range, which, from the previous discussion of future travel requirements may not be needed, this performance could be traded for additional payload capability, noise suppression, and other areas of concern.

A HYPERSONIC RESEARCH AIRPLANE

Finally, the case for a hypersonic research airplane, as stated by Becker and Kirkham (ref. 11) is given. "Although promising new approaches are being pursued in all the disciplines, there are of course several major deficiencies, chief among which are the lack of a proven power plant and the lack of a proven practical structural concept. Probably the most serious deficiency is the absence of any real flight vehicle development. Past experience suggests that progress beyond the present stage will be slow until the development of an actual vehicle is undertaken. In previous situations of this kind where it is obviously too soon for a full-scale prototype, the research airplane has been used to great advantage to provide the necessary focus, stimulus, and resource levels. The X-15 program, for example, provided the first great impetus to hypersonics and manned space flight technology.

"Figure 23 presents a concept and specifications for a small research airplane which can be thought of as a 1/3 scale version of the hypersonic transport. Air-breathing research scramjet engines and wing panels which could embody a variety of structural concepts are principal features. The vehicle would be capable of about 5 minutes cruise at Mach 8 either on its primary rocket propulsion or with the research scramjets. Present technology would fully support the development of such a vehicle. Both the analytical and the experimental tools are available. No new national facilities would be needed.

"The technology base developed with a hypersonic research airplane would make it possible to proceed with confidence to a full-scale prototype hypersonic transport or other applications including airbreathing launch systems."

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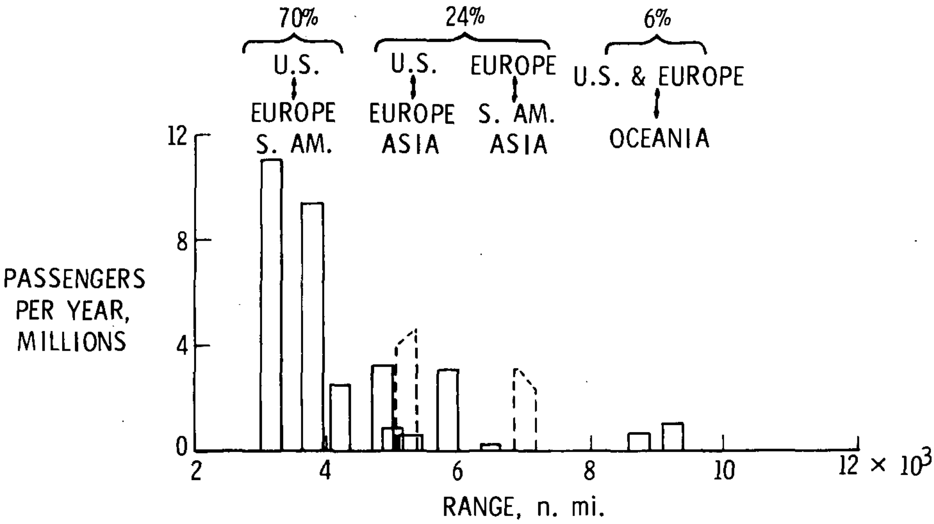


Figure 1.- Projected 1990 intercontinental air traffic.

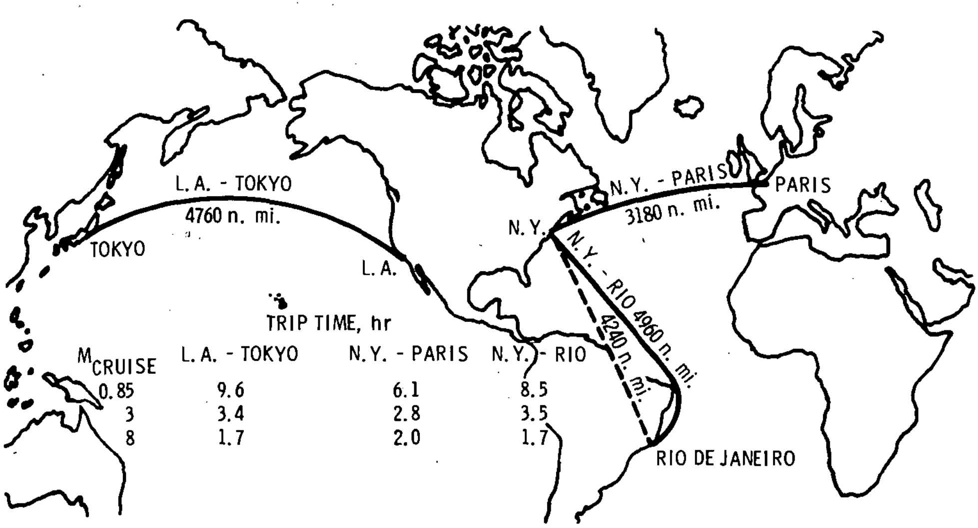


Figure 2.- Effect of aircraft speed on trip time.

PROPERTY	LIQUID HYDROGEN	METHANE	JP - 4
HEAT OF COMBUSTION, Btu/lb	51 600	21 500	18 600
HEAT SINK CAPABILITY TO 1000° F, Btu/lb	5 100	1 100	165*
LIQUID DENSITY, lb/ft^3	4.4	26.4	50.0

*JP - 4 HEAT SINK TO 375° F

Figure 3.- Comparison of fuel characteristics (from ref. 4).

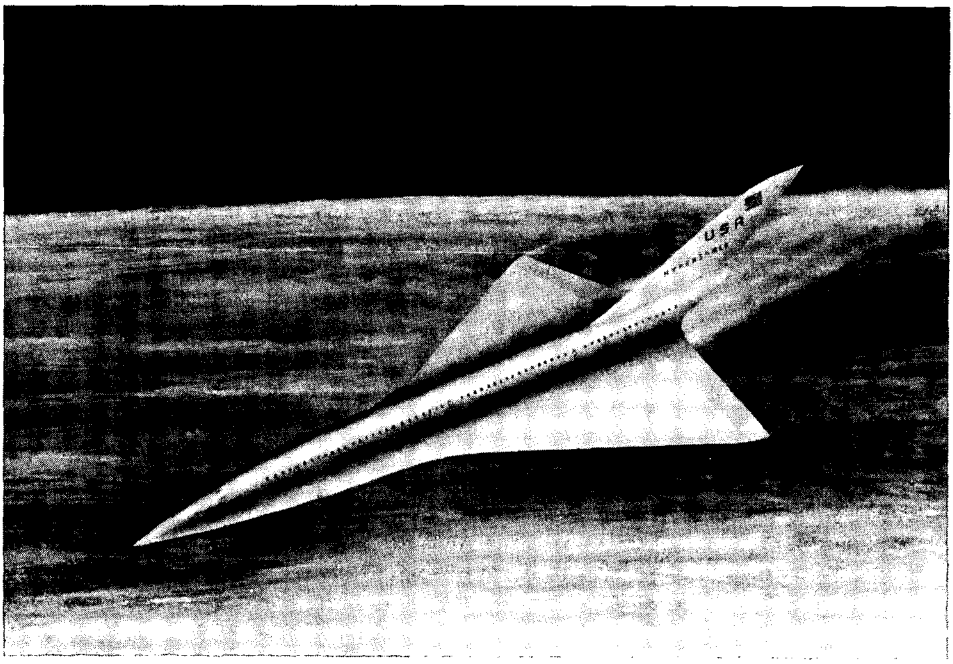


Figure 4.- Hypersonic air-breathing transport.

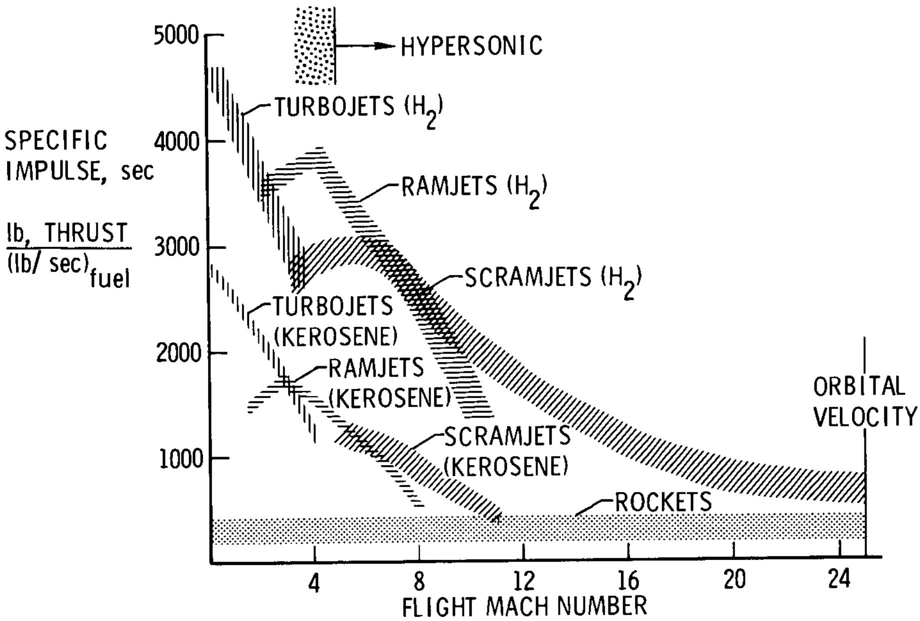


Figure 5.- Specific impulse for air-breathing engines and rockets.

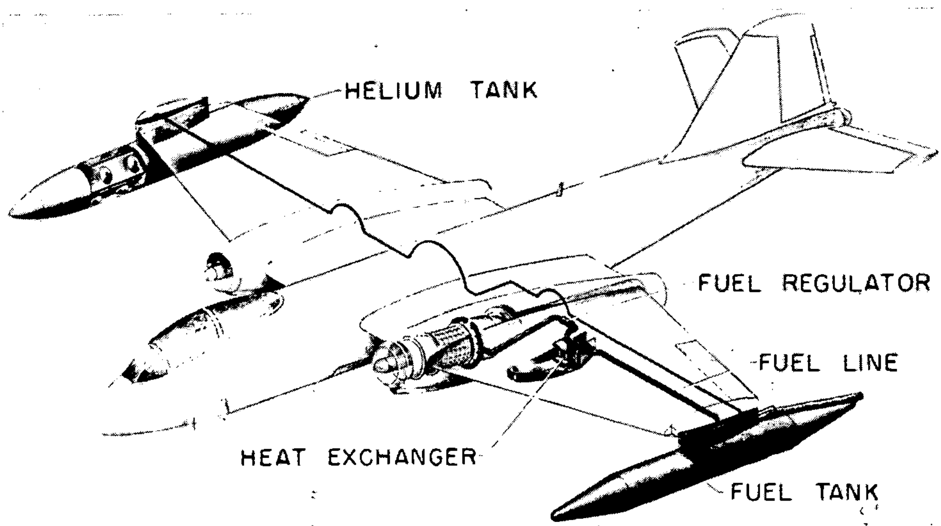


Figure 6.- Hydrogen system for B-57 airplane.

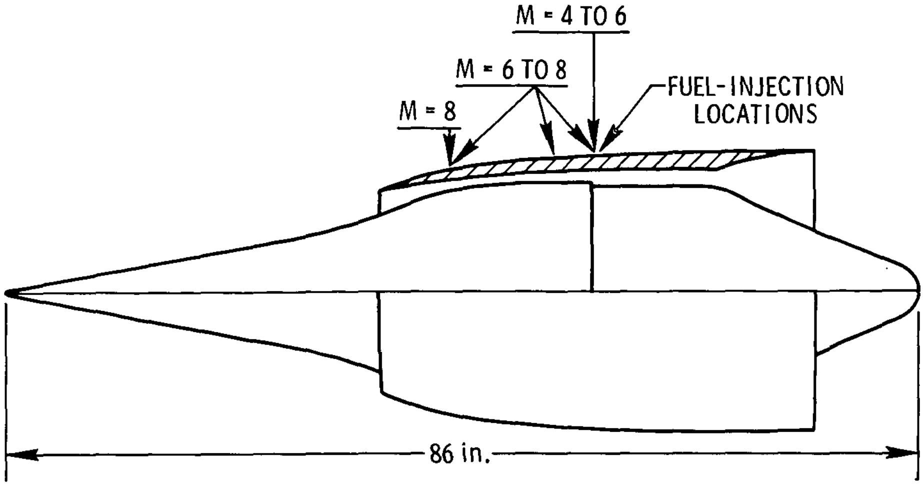


Figure 7.- Langley hypersonic research engine.

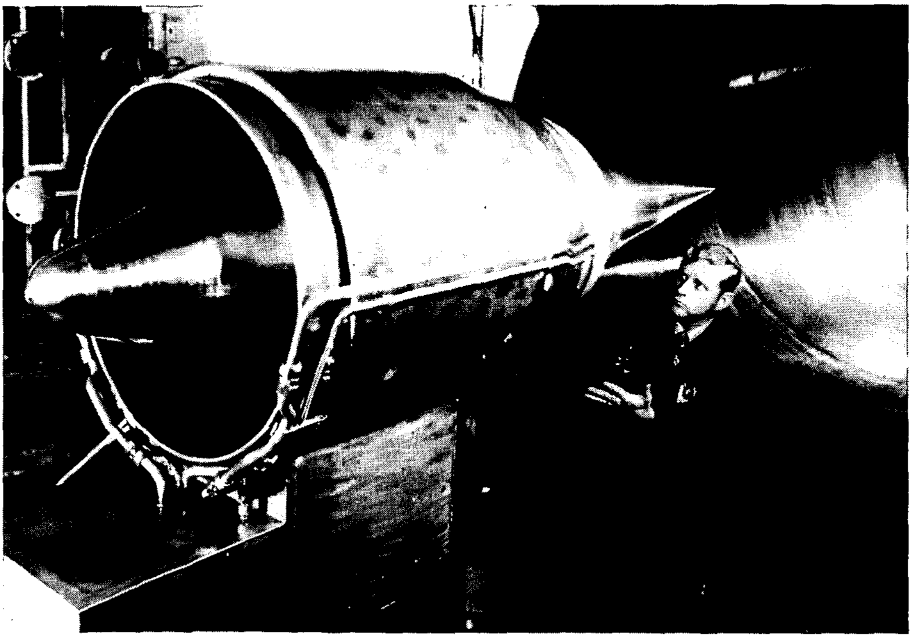


Figure 8.- HRE installed in Langley 8-foot high-temperature structures tunnel for tests.

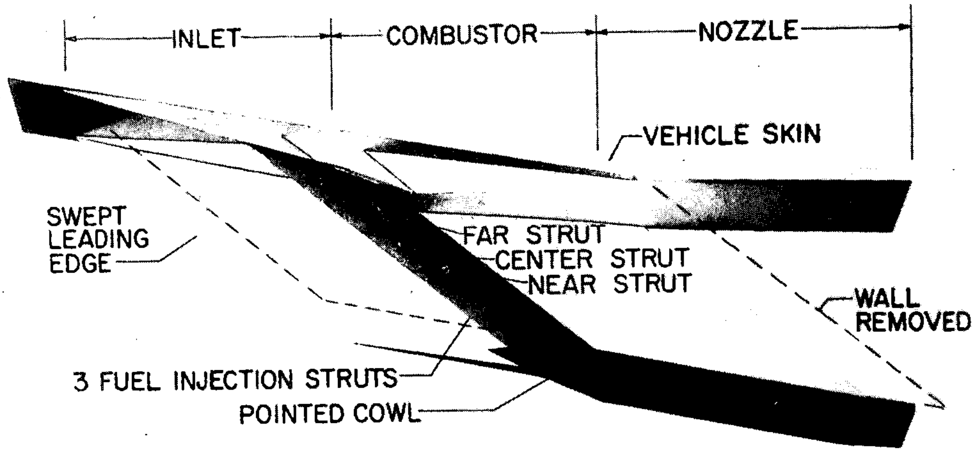


Figure 9.- Langley 3-D scramjet module.

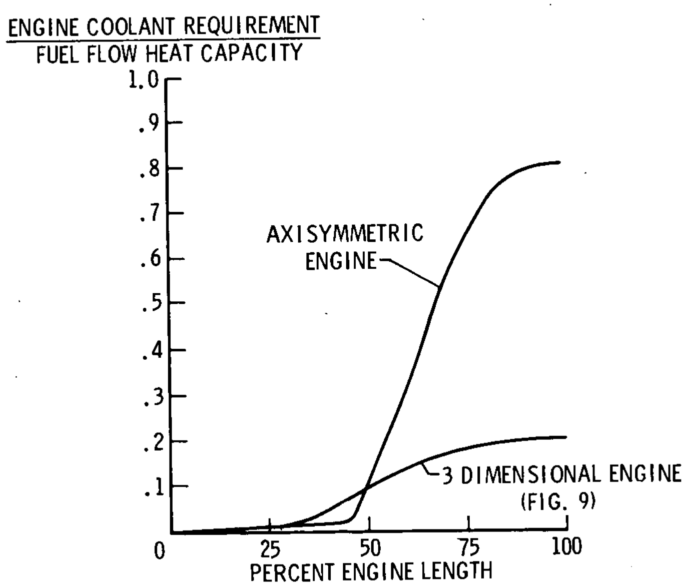


Figure 10.- Comparison of engine cooling requirements for 3-D module and axisymmetric engines. Mach 6, capture area 39.1 sq ft, altitude 112,000 ft, supersonic-stoichiometric combustion.

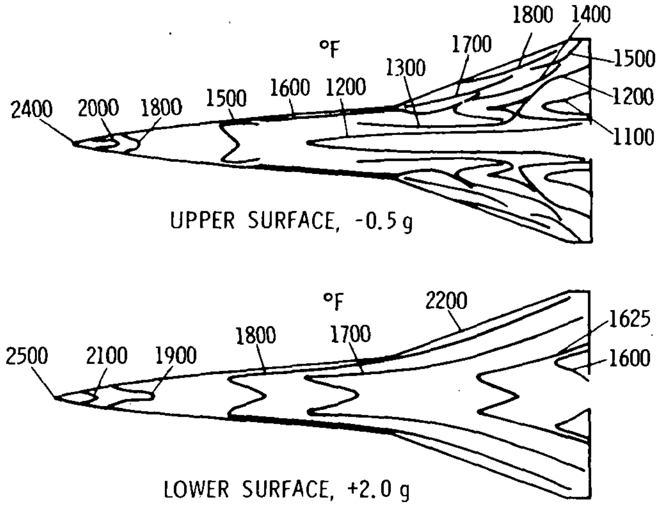


Figure 11.- Typical temperature distribution for radiation cooled hot structure. Mach 8, altitude 90,000 ft.

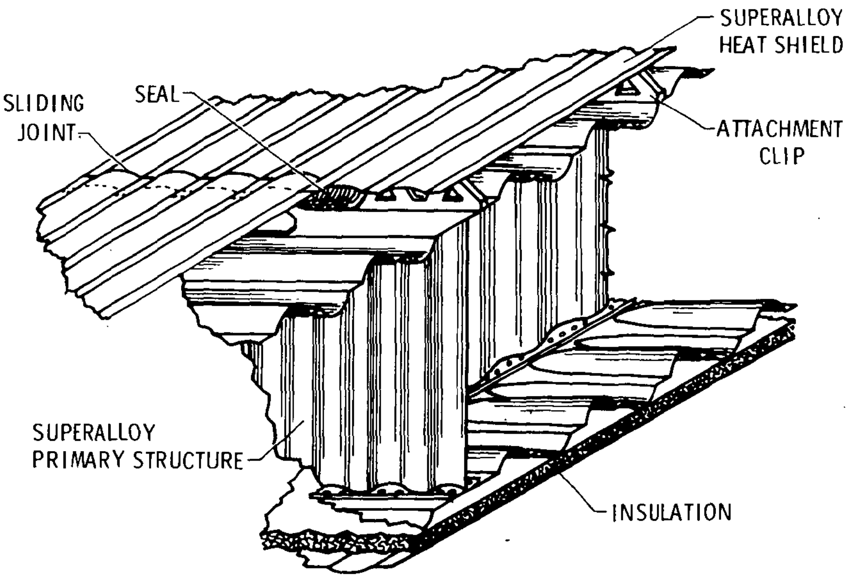


Figure 12.- Cruise vehicle hot wing structure.

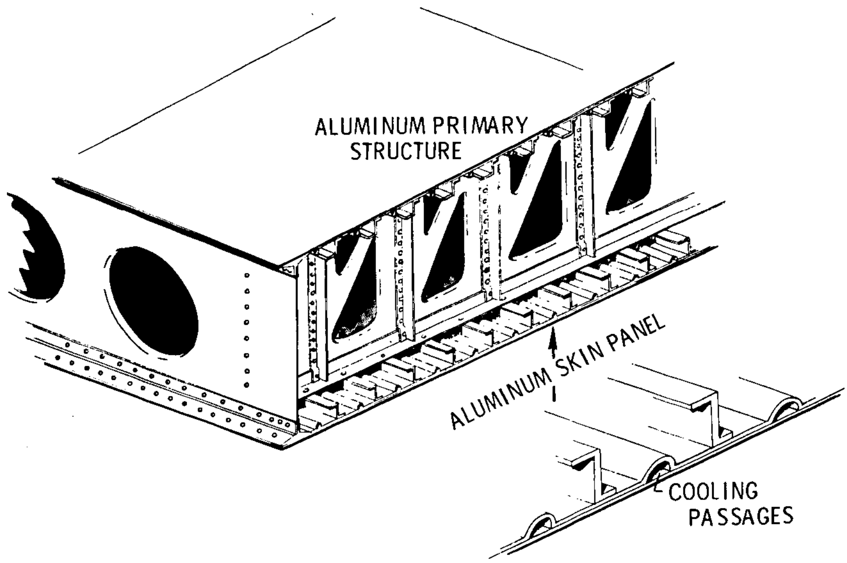


Figure 13.- Cooled wing structure.

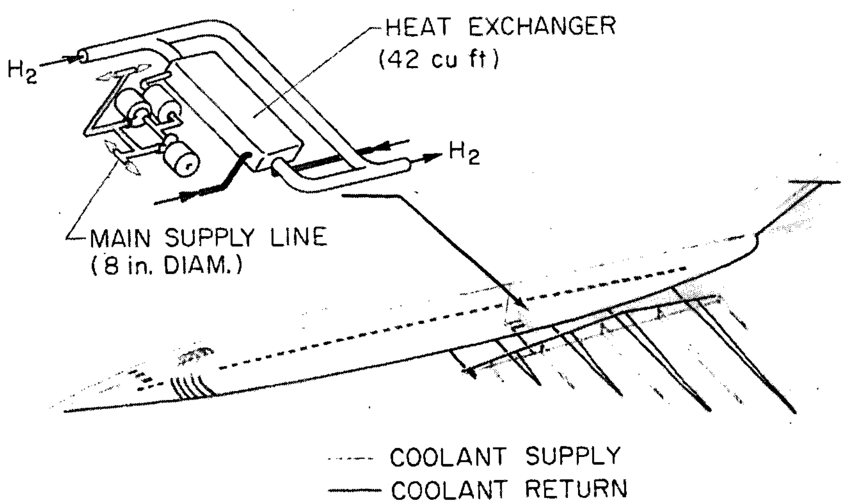
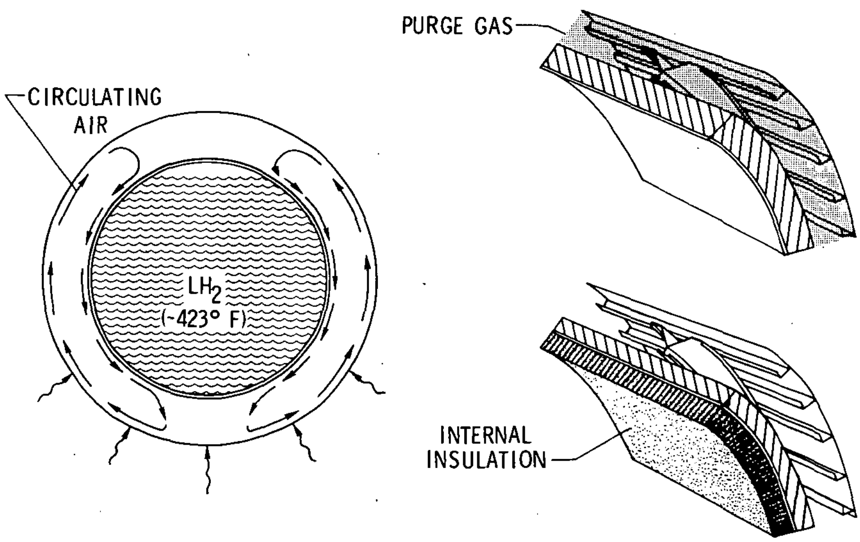


Figure 14.- Aircraft cooling system.

	$W_{COOLED} - W_{HOT}$, kg	(lb)
• PIPING AND COOLANT	+4 400	(+9 800)
• PUMPS, FUEL, MISC.	+1 100	(+2 500)
• HEAT EXCHANGER	+700	(+1 600)
• AIRFRAME	-10 100	(-22 300)
• HEAT SHIELDS AND INSULATION	-6 500	(-14 400)
NET CHANGE:	-10 400	(-22 800)

Figure 15.- Cooled versus hot structure – typical weight differences. (600,000 lb gross weight.)



CRYOGENIC PUMPING

Figure 16.- Thermal protection of liquid hydrogen tanks.

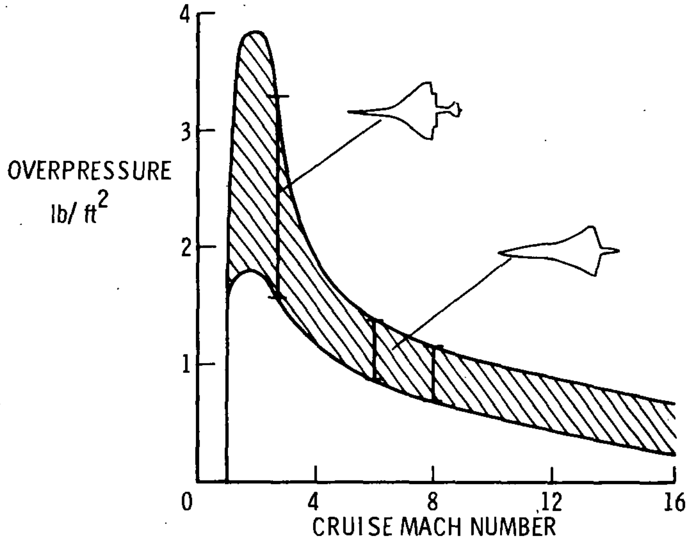


Figure 17.- Sonic-boom overpressures.

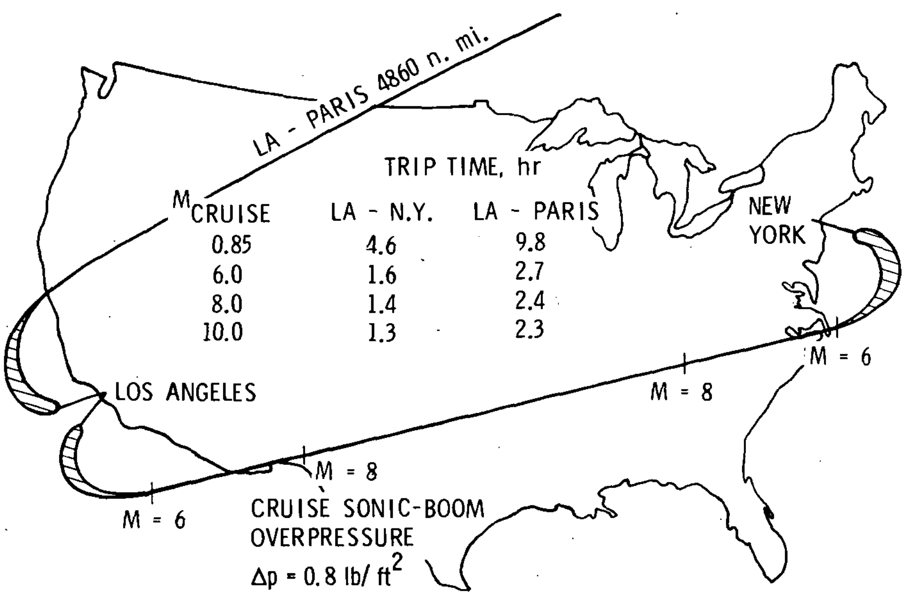


Figure 18.- Overland operation.

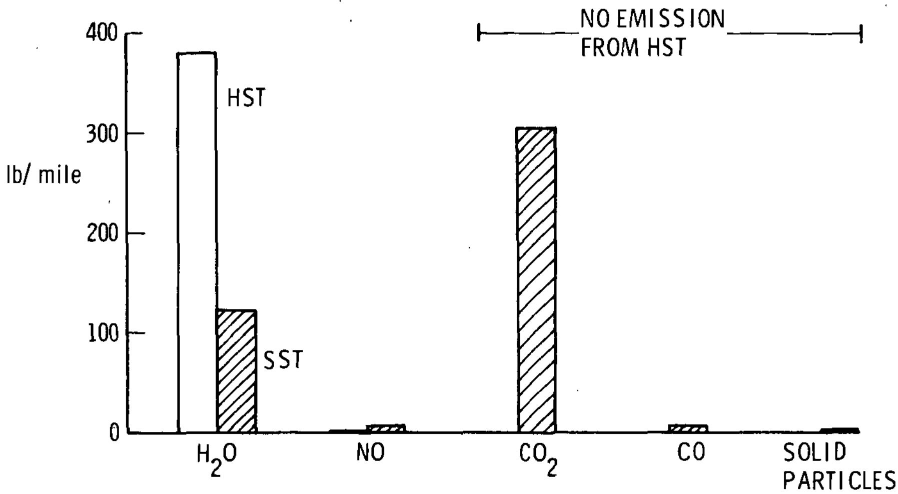


Figure 19.- Environmental emissions in cruise. (750,000 lb gross weight.)

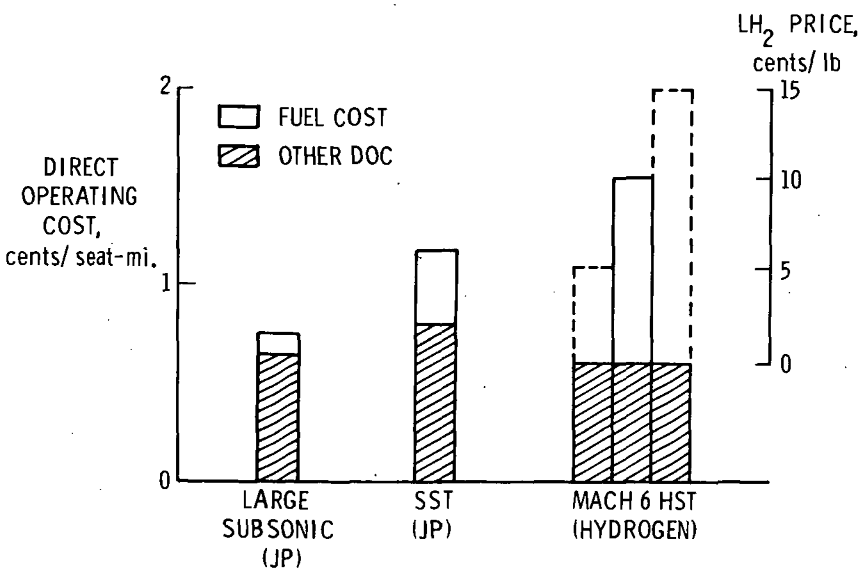


Figure 20.- Comparison of direct operating cost. Range, 4600 st. mi.

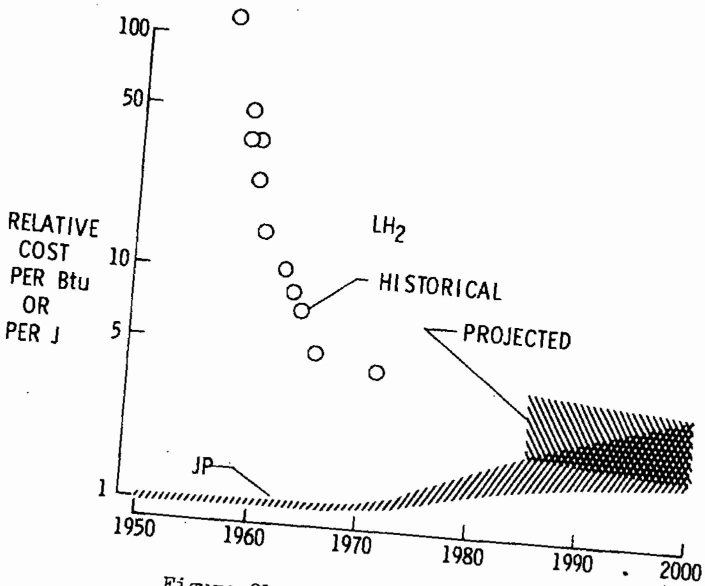


Figure 21.- Future fuel cost.

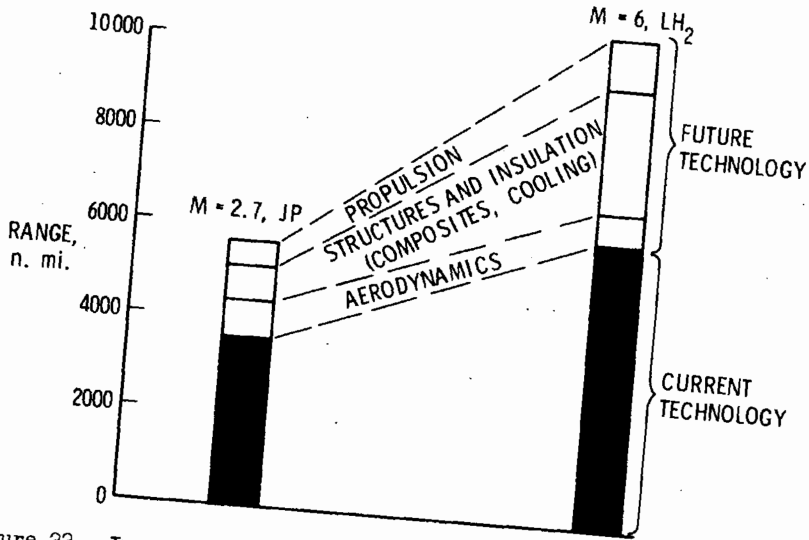
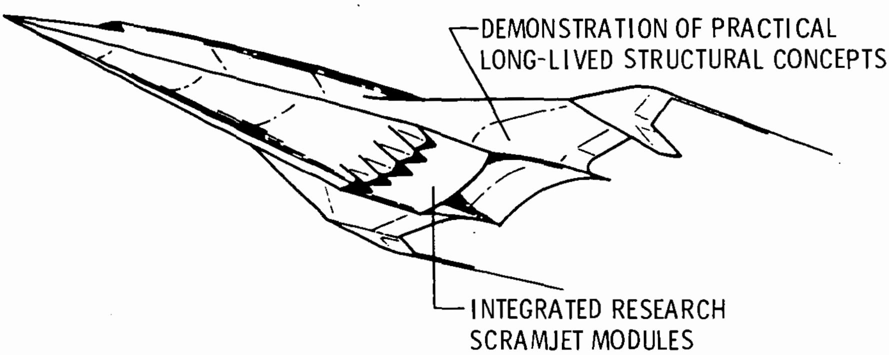


Figure 22.- Impact of future technology. (750,000 lb gross weight; 300 passengers.)



- GROSS TAKE-OFF WEIGHT ≈ (80 000 lb)
- LENGTH ≈ (80 ft)
- CONVENTIONAL TAKE-OFF AND LANDING
- MAXIMUM SPEED, M = 8 TO 12
- EXISTING ROCKET (PRIME PROPULSION)
- MODULAR RESEARCH AIRBREATHING ENGINES
- 5-MINUTE CRUISE AT MAXIMUM SPEED

Figure 23.- Research airplane concept and specifications.

MEMBERSHIP IN THE DIVISION OF FUEL CHEMISTRY

The Fuel Chemistry Division of the American Chemical Society is an internationally recognized forum for scientists, engineers, and technical economists concerned with the conversion of fuels to energy, chemicals, or other forms of fuel. Its interests center on the chemical problems, but definitely include the engineering and economic aspects as well. Further, the Division is strengthening its coverage of areas of air and water pollution, gasification, and related areas.

Any chemist, chemical engineer, geologist, technical economist, or other scientist concerned with either the conventional fossil fuels, or the new high-energy fuels--whether he be in government, industry, or independent professional organization--would benefit greatly from participation in the progress of the Fuel Chemistry Division.

The Fuel Chemistry Division offers at least two annual programs of symposia and general papers, extending over several days, usually at National Meetings of the American Chemical Society. These include the results of research, development, and analysis in the many fields relating to fuels which are so vital in today's energy-dependent economy. Members of the Division have the opportunity to present papers of their own, or participate in discussions with experts in their field. Most important, the Fuel Chemistry Division provides a permanent record of all of this material in the form of preprints, which are sent free to all members several weeks before each meeting.

Symposia of significant content and broad interest have been published as part of the Advances in Chemistry Series and by other scientific book publishers. Landmark symposia on Fuel Cells, Advanced Propellant Chemistry, Gasification, and Spectrometry are already in print. When these volumes are available they are usually offered first to Division members at greatly reduced cost.

In addition to receiving several volumes of preprints each year, as well as regular news of Division activities, benefits of membership include: (1) Reduced subscription rates for "Fuel" and "Combustion and Flame," (2) Reduced rates for volumes in the "Advances in Chemistry Series" based on Division symposia, and (3) The receipt card sent in acknowledgment of Division dues is good for $1.00 toward a complete set of abstracts of all papers presented at each of the National Meetings.

To join the Fuel Chemistry Division as a regular member, one must also be or become a member of the American Chemical Society. Those not eligible for ACS membership because they are not practicing scientists, engineers, or technical economists in areas related to chemistry, can become Division Affiliates. They receive all benefits of a regular member except that they cannot vote, hold office, or present other than invited papers. Affiliate membership is of particular value to those in the information and library sciences who must maintain awareness of the fuel area. Non-ACS scientists active in the fuel area and living outside of the United States are also invited to become Division Affiliates.

Membership in the Fuel Chemistry Division costs only $4.00 per year, or $11.00 for three years, in addition to ACS membership. The cost for a Division Affiliate, without joining ACS, is $10.00 per year. For further information write to:

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Secretary-Treasurer
ACS Division of Fuel Chemistry
Pennsylvania State University
109 Mineral Industries Building
University Park, Pennsylvania 16802
Telephone: Area 814 - 865-2372

RECENT FUEL DIVISION SYMPOSIA

Volume	Title	Presented At
Vol. 14, No. 1	Symposium on Coal and Coal Based Carbons Symposium on Petrographic, Chemical, and Physical Properties of Coal	Toronto, Canada May, 1970
Vol. 14, No. 2	Symposium on Coal Combustion in Present and Future Power Cycles	Toronto, Canada May, 1970
Vol. 14, No. 3	Synthetic Fuels Symposium No. 3 - Economics of Solid Fuel Conversion Processes General Papers	Chicago, Illinois September, 1970
Vol. 14, No. 4 Parts I and II	Symposium on Hydrogen Processing of Solid and Liquid Fuels	Chicago, Illinois September, 1970
Vol. 14, No. 5	Symposium on High Temperature and Rapid Heating Reactions of Fuels	Chicago, Illinois September, 1970
Vol. 15, No. 1	Symposium on Shale Oil, Tar Sands and Related Materials	Los Angeles March, 1971
Vol. 15, No. 2	Symposium on Combustion Symposium on Pollution Control in Fuel Combustion, Mining and Processing	Washington, D. C. September, 1971
Vol. 15, No. 3	Symposium on Gasification of Coal General Papers	Washington, D. C. September, 1971
Vol. 16, No. 1	Symposium on Quality of Synthetic Fuels, Especially Gasoline and Diesel Fractions, and Pipeline Gas	Boston, Mass. April, 1972
Vol. 16, No. 2	Symposium on Preparation and Properties of Catalysts for Synthetic Fuel Production General Papers	Boston, Mass. April, 1972
Vol. 16, No. 3	Symposium on Modern Methods of Fuel Analysis	Boston, Mass. April, 1972
Vol. 16, No. 4	Symposium on Non-Fossil Chemical Fuels	Boston, Mass. April, 1972

DIVISION OF FUEL CHEMISTRY

PROJECTED PROGRAMS

Environmental Pollution Control - Part I. Removal of Oxides of Sulfur and Nitrogen from Combustion Product Gases Robert M. Jimeson	New York, N. Y. August, 1972
Environmental Pollution Control - Part II. Removal of Sulfur from the Fuel Robert M. Jimeson	New York, N. Y. August, 1972
Storch Symposium	New York, N. Y. August, 1972
General Papers Wendell H. Wiser	New York, N. Y. August, 1972
Symposium on the Power Industry of the Future - Fossil and Fission Fuels Joint with IEC Division - Develop by IEC	New York, N. Y. August, 1972
Novel Combined Power Cycles S. Fred Robson	Dallas, Texas April, 1973
Fuel from Waste Products H. R. Appell	Dallas, Texas April, 1973
Carbon Monoxide Production and New Uses J. S. Mackay	Dallas, Texas April, 1973
Synthetic Fuel Gas Purification H. S. Vierk	Dallas, Texas April, 1973
Coal Gasification L. G. Massey	Dallas, Texas April, 1973
General Papers F. Schora	Dallas, Texas April, 1973